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THE EFFECTS OF MONETARY POLICY "NEWS" AND "SURPRISES"

FABIO MILANI AND JOHN TREADWELL

University of California, Irvine

Abstract. There is substantial agreement in the monetary policy literature over the effects of exogenous monetary policy shocks. The shocks that are investigated, however, almost exclusively represent unanticipated changes in policy, which surprise the private sector and which are typically found to have a delayed and sluggish effect on output.

In this paper, we estimate a New Keynesian model that incorporates news about future policies to try to disentangle the anticipated and unanticipated components of policy shocks. The paper shows that the conventional estimates confound two distinct effects on output: an effect due to unanticipated or "surprise" shocks, which is smaller and more short-lived than the response usually obtained in the literature, and a large, delayed, and persistent effect due to anticipated policy shocks or "news".

News shocks play a larger role in influencing the business cycle than unanticipated policy shocks, although the overall fraction of economic fluctuations that can be attributed to monetary policy remains limited.

Keywords: Anticipated and Unanticipated Monetary Policy Shocks; News Shocks; New Keynesian Model with News Shocks; Effects of Monetary Policy on Output.

JEL classification: E32, E52, E58.

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Address for correspondence:
Fabio Milani: Department of Economics, 3151 Social Science Plaza, University of California, Irvine, CA 92697-5100. *Phone:* 949-824-4519. *Fax:* 949-824-2182. *E-mail:* fmilani@uci.edu. *Homepage:* http://www.socsci.uci.edu/~fmilani.
John Treadwell: Department of Economics, 3151 Social Science Plaza, University of California, Irvine, CA 92697-5100. *E-mail:* jtreadwe@uci.edu.

1. Introduction

There is widespread agreement in the economics profession regarding the effects of monetary policy shocks. Christiano, Eichenbaum, and Evans (1999) survey the research on the topic and show that the conclusions it delivers are remarkably robust to a number of different assumptions. The pattern of the output and inflation responses to a monetary policy shock derived from structural VARs, regardless of whether the VARs include few endogenous variables or a much larger information set (e.g., Bernanke, Boivin, and Eliasz, 2005, Belviso and Milani, 2006), are roughly similar whether shocks are identified using the recursiveness assumption (Sims, 1980), sign restrictions (e.g., Uhlig, 2005, Canova and De Nicolo', 2002), restrictions based on a model for the market of bank reserves (e.g., Bernanke and Mihov, 1998), or a narrative approach (e.g., Romer and Romer, 2004). As the VAR evidence is rather coherent, the structural models that have been developed in the past years needed, at a minimum, to be able to match the responses to monetary shocks. Christiano, Eichenbaum, and Evans (2005) develop a medium-scale sticky-price model, which is estimated to match the impulse responses from a VAR. The model successfully manages to approximate the response of macroeconomic variables to an exogenous monetary policy shock. Smaller-scale models are similarly successful (e.g., Giannoni and Woodford, 2003), provided that they include now popular features such as habit formation in consumption and indexation to past inflation in price setting.

In the vast majority of cases, after a monetary policy shock output displays a hump-shaped response with a peak after between five to eight quarters, which gradually dies out in about five years. Another robust finding from the empirical literature is that monetary policy provides only a small contribution to output fluctuations (from forecast error variance decompositions, generally between 5 and 30% of the output variance can be attributed to monetary policy shocks).

The type of shock that is almost always considered in the literature (both in structural VARs and in general equilibrium models) is an exogenous shock to monetary policy, which is unanticipated by the private sector. But in reality, anticipated changes may be equally important. Anticipations may result from explicit central bank communication, aimed at signaling upcoming deviations from the historical monetary policy practice,[1] or they may simply reflect private sector's own views about future policy innovations, which will not necessarily need to materialize.

This paper aims to disentangle the effects of unanticipated or "surprise" shocks to monetary policy and the effects of anticipated shocks, or "news".

The analysis of unanticipated versus anticipated innovations to monetary policy in a VAR context would be problematic. If anticipated future monetary policy decisions matter, in fact, the estimated VAR would suffer from the same invertibility problem identified by Leeper et al. (2008) for the case of anticipated fiscal policy. The obstacles to a typical VAR approach arise from the misalignment between the information set available to the agents in the economy and the information set available to the econometrician, when anticipations matter. The VAR econometrician cannot extract the news component in the agents' information set, nor can the econometrician retrieve the correct structural shocks by using current and past observable data. Agents in the economy and the econometrician have a different discounting: while agents discount current news more heavily, as they refer to events that will happen further in the future, the econometrician discounts them less than older news. The different discounting is at the heart of the non-invertibility problem.

While a large part of the literature has stressed the role of anticipations in studying the effects of fiscal policy, the same obstacles are present in the analysis of monetary policy (a point also noted in Leeper et al., 2008). Central banks often provide direction about future policies, and the private sector routinely employs considerable resources into anticipating future monetary policy decisions.

Therefore, we choose to analyze the role of news versus surprises in monetary policy adopting a structural general equilibrium specification.[2] The model allows us to identify the anticipated and unanticipated shocks, conditioning on the model and news structure specification.

We estimate a benchmark New Keynesian model in order to compare the response of output to policy surprises and news, and to study their contribution to the business cycle. The modeling of news shocks is in the spirit of Schmitt-Grohe' and Uribe (2008) and Fujiwara et

[1]For example, in 2003, the FOMC announced that "*policy accommodation can be maintained for a considerable period*" while FOMC statements during the 2008-2009 financial crisis retained a sentence to indicate that economic conditions "*warrant exceptionally low levels of the federal funds rate for an extended period*".

[2]Moreover, we show later in the paper that VARs are, in fact, unable to identify the structural shocks from the DSGE model, when news components are present.

al. (2011). While these papers, as others in the “news” view of the business cycle literature (e.g., Beaudry and Portier, 2006, Jaimovich and Rebelo, 2009), mostly emphasize news about future technology changes, this paper focuses, instead, on news about future monetary policy shocks.[3]

When monetary policy shocks are assumed to include an anticipated component, the effects of monetary policy shocks depart from those usually found in the literature. Monetary policy surprises lead to a smaller and more short-lived response of output than the one indicated by the conventional estimates that disregard anticipated policy changes. News shocks have a larger, delayed, and more persistent effect. News at the one-year anticipation horizon appears to play the most significant role, but longer horizons also matter.

News shocks account for a larger share of fluctuations than do the surprise shocks on which the literature has mostly focused. News accounts for 15-25% of medium-run output fluctuations, depending on the specification, while surprise shocks contribute to less than 2% of fluctuations. Overall, however, monetary policy shocks are confirmed to not be a major contributor to business cycles.

In the estimation of models with news an important component is the choice of the anticipation horizon. In this paper, we take an agnostic approach and estimate the model under an extensive range of alternative horizons and model specifications.[4] The model comparison exercise indicates that, in the baseline model, the best-fitting specification includes news about future monetary policy shocks at horizons equal to four, eight, and twelve quarters ahead. The models that allow for news about future monetary policies lead to significant improvements in fit compared with the benchmark model with only unanticipated shocks. The paper's results are robust to assuming permanent shocks to monetary policy, in the form of shocks to the central bank's inflation target, and news about non-policy demand and supply shocks.

While unanticipated shocks are predominant in the monetary policy literature, the distinction between unanticipated and anticipated shocks has been considered in the past. Cochrane (1998) and Hoover and Jorda (2001) show how the anticipated/unanticipated assumption may influence the conclusions on the real effects of monetary policy. Early empirical work by

[3]A recent exception is the paper by Matsumoto et al. (2008), who consider the effect of one-period-ahead news about monetary policy on exchange rates and equity returns. Schmitt-Grohe' and Uribe (2008) also consider news about future government spending.

[4]Fujiwara et al. (2011) use a similar approach to choose the best-fitting horizon regarding technology “news”.

Mishkin (1982), using a reduced-form model, finds that anticipated changes in policy matter. Our results are consistent with his conclusions.

The role of anticipated policy has been studied more often in the context of fiscal, particularly tax, policy (e.g., Leeper et al., 2008, Mertens and Ravn, 2010). This paper shows that anticipations about future monetary policies are also critical and should be more generally taken into account.

2. The Model

We adopt a prototypical New Keynesian model, which assumes that the economy can be summarized as follows:

$$x_t = \frac{1}{1+\phi}E_t x_{t+1} + \frac{\phi}{1+\phi}x_{t-1} - \frac{\sigma(1-\phi)}{1+\phi}\left(i_t - E_t\pi_{t+1}\right) + g_t \quad (2.1)$$

$$\pi_t = \frac{\beta}{1+\beta\gamma}E_t\pi_{t+1} + \frac{\gamma}{1+\beta\gamma}\pi_{t-1} + \frac{\xi}{(1+\beta\gamma)}\left(\omega x_t + \frac{\sigma^{-1}}{(1-\phi)}(x_t - \phi x_{t-1})\right) + \mu_t \quad (2.2)$$

$$i_t = \rho i_{t-1} + (1-\rho)\left[\chi_\pi \pi_t + \chi_x x_t\right] + \nu_t, \quad (2.3)$$

where x denotes the output gap, π denotes inflation, i denotes the nominal interest rate (similar small-scale New Keynesian models have been used in Dennis, 2004, 2009, and Giannoni and Woodford, 2003, among others).

Equation (1) is an intertemporal Euler equation obtained from a linear approximation to households' optimal choice of both consumption and bond holdings, where the parameter σ represents the intertemporal elasticity of substitution. The equation is obtained by assuming (external) habit formation in consumption, with ϕ denoting the habits coefficient. The current output gap depends on the expected and lagged output gaps and on the ex-ante real interest rate. The net effect of exogenous shifts on the Euler equation is captured by the demand disturbance g_t.

Production in the economy is carried out by a continuum of monopolistically-competitive firms, each facing a downward-sloping demand curve for its differentiated output. Prices are sticky due to a Calvo-type rigidity, with $(1-\alpha)$ denoting the fraction of firms able to re-optimize their price in a given period. Equation (2) is a New Keynesian Phillips curve and describes inflation dynamics in the economy, where $0 < \beta < 1$ represents the households' discount factor and where $\xi \equiv \frac{(1-\alpha)(1-\alpha\beta)}{\alpha} > 0$. The firms that are not allowed to set their price optimally in a given period are assumed to update their price according to the previous quarter aggregate inflation rate; the coefficient γ denotes the degree of price indexation to past inflation. Current inflation is a function of both the expected and lagged inflation rate. Habit formation also affects the Phillips curve: inflation no longer depends exclusively on the current output gap x_t, but also depends on the term $(x_t - \phi x_{t-1})$. The process μ_t captures exogenous shifts in the marginal cost of production.

Equation (3) describes a Taylor rule. The parameter ρ represents the degree of monetary policy inertia, while χ_π denotes the monetary authorities' response to inflation and χ_x denotes the response to the output gap. The process ν_t captures exogenous deviations from the systematic policy rule. We assume that the disturbances g_t, μ_t, and ν_t evolve according to:

$$g_t = \rho_g g_{t-1} + \varepsilon_t^g \tag{2.4}$$

$$\mu_t = \rho_\mu \mu_{t-1} + \varepsilon_t^\mu \tag{2.5}$$

$$\nu_t = \rho_\nu \nu_{t-1} + \varepsilon_t^\nu + \sum_{h=1}^{H} \eta_{t-h}^{\nu,h} \tag{2.6}$$

where the ε_t^i terms, $i = g,\ \mu,\ \nu$, in each equation, represent unanticipated *i.i.d.*, zero mean, finite-variance, fundamental innovations, $\varepsilon_t^i \sim N(0, \sigma_i^2)$. Both g_t and μ_t evolve according to univariate AR(1) processes with autoregressive coefficients ρ_g and ρ_μ.[5] The policy disturbance ν_t is also allowed to be serially correlated, with autoregressive coefficient ρ_ν (English et al., 2003, in fact, show that both a partial adjustment term in the Taylor rule and autocorrelated shocks matter in the data); the expression for the policy disturbance includes both unanticipated (ε_t^ν) and anticipated innovations ($\eta_{t-h}^{\nu,h}$). Each term $\eta_{t-h}^{\nu,h}$ denotes a "news" shock about future monetary policy, which is known to private agents in period $t-h$, but will materialize only h periods ahead. Since the choice of the news horizon h may be arbitrary, the paper will assess different combinations of news horizons in the empirical analysis, up to a maximum horizon H equal to twelve quarters (which, at the moment, is a limit for our computational capabilities). As in Schmitt-Grohe and Uribe (2008), all shocks are assumed to be uncorrelated.

The surprise shock ε_t^ν has the usual interpretation of a deviation from the Taylor rule that is completely unexpected by the private sector. News shocks, instead, capture future deviations of monetary policy from the Taylor rule that are either credibly announced by the central bank, or, at least, anticipated by the private sector, even if they subsequently fail to materialize. Anticipated shocks about future monetary policies affect the expectations

[5]We have experimented in the estimation with correlated g_t and μ_t, but the conclusions were unchanged

about future macroeconomic variables that consumers and firms need to form in order to solve their consumption and price-setting decisions. Hence, the identification of news shocks versus surprise shocks works through this expectational channel: news influences future expectations, while surprise shocks do not.

We choose to work with a simple small-scale model, since the inclusion of news shocks substantially expands the state space. Moreover, since the New Keynesian model in the paper still constitutes an important benchmark for the analysis of monetary policy, we think its use will render the implications of disentangling surprise and news shocks in the estimation as transparent as possible. We introduce habit formation in consumption and inflation indexation in price setting, since they are typically necessary to match the hump-shaped response of output and the sluggish response of inflation to monetary and other shocks; these features have become ubiquitous in empirical models. But, given our choice to consider the role of news in a benchmark monetary model, we maintain its simplifying assumptions of a fixed capital stock and the absence of frictions in the labor market.

3. Econometric Approach

The model parameters $\Theta = [\phi, \gamma, \alpha, \rho, \chi_\pi, \chi_x, \rho_g, \rho_\mu, \rho_\nu, \sigma_g, \sigma_\mu, \sigma_\nu, \sigma_{\eta,h=h_1}, ..., \sigma_{\eta,h=H}]$ are estimated using likelihood-based Bayesian methods and U.S. data on the output gap, inflation, and the federal funds rate as observable variables. The output gap is calculated as the percentage deviation of Real GDP from Potential GDP (Congressional Budget Office's estimate) and inflation as the quarterly change in the GDP Implicit Price Deflator, while the federal funds rate is used in levels (and adjusted to refer to a quarterly interest rate). The sample spans the period from 1960:q1 to 2009:q1. The priors are shown in Table 1. We assume a Beta prior distribution for the parameters that should be bounded between 0 and 1. We assume inverse Gamma prior distributions for the standard deviations of surprise and news shocks: those regarding monetary policy are assigned the same prior means and variances. A previous version of the paper considered uninformative Uniform priors for the standard deviations of news shocks and obtained the same conclusions: the corresponding results are now reported in the robustness section. We fix the coefficient summarizing the elasticity of marginal cost to income ω to 2 and the elasticity of substitution among differentiated goods θ to 11, implying a steady-state mark-up equal to 10% (not all coefficients are separately identifiable from the

TABLE 1. Prior Distributions

		Prior Distribution			
Description	Param.	Dist.	Supp.	Mean	95% Prior Interval
Calvo price stick.	α	B	$[0,1]$	0.6	[0.31,0.85]
MP Inertia	ρ	B	$[0,1]$	0.7	[0.32,0.96]
MP Inflation feedback	χ_π	N	$\mathbb{R}$	1.5	[1.01,1.99]
MP Output feedback	χ_x	N	$\mathbb{R}$	0.25	[0.01,0.49]
Habit Formation	ϕ	B	$[0,1]$	0.7	[0.32,0.96]
Price Indexation	γ	B	$[0,1]$	0.7	[0.32,0.96]
AR coeff. g_t	ρ_g	B	$[0,1]$	0.5	[0.09,0.91]
AR coeff. μ_t	ρ_μ	B	$[0,1]$	0.5	[0.09,0.91]
AR coeff. ν_t	ρ_ν	B	$[0,1]$	0.5	[0.09,0.91]
Std. Demand Shock	σ_g	Γ^{-1}	$\mathbb{R}^+$	0.4	[0.07,1.65]
Std. Cost-Push Shock	σ_μ	Γ^{-1}	$\mathbb{R}^+$	0.1	[0.019,0.40]
Std. Surprise MP Shock	σ_ν	Γ^{-1}	$\mathbb{R}^+$	0.1	[0.019,0.40]
Std. h-quarters News Shock	$\sigma_{\eta,h}$	Γ^{-1}	$\mathbb{R}^+$	0.1	[0.019,0.40]

Notes: the table reports prior means and 95% prior probability intervals, along with posterior mean estimates for each parameter and the corresponding 95% Highest Posterior Density (HPD) intervals. The symbols in the table denote the following prior distribution: U= Uniform, N= Normal, B= Beta, Γ^{-1}= Inverse Gamma.

estimation). The coefficient σ is assumed equal to 1 (in a model with habit formation, the pseudo-intertemporal elasticity of substitution is given by $\sigma(1-\phi)$, which remains estimated, rather than by σ alone).

News shocks are incorporated in the model as in Schmitt-Grohe' and Uribe (2008), Fujiwara et al. (2011), and Khan and Tsoukalas (2009). The model can be represented in state-space form as

$$\Gamma_0\xi_t = \Gamma_1\xi_{t-1} + \Psi w_t + \Pi\zeta_t, \tag{3.1}$$

where $\xi_t = \left[x_t, \pi_t, i_t, E_t x_{t+1}, E_t\pi_{t+1}, g_t, \mu_t, \nu_t, \eta_t^1, ..., \eta_t^H, \eta_{t-1}^2, ..., \eta_{t-1}^H, ..., \eta_{t-H+1}^H, \right]'$, for the generic case including all news horizons $1 \leq h \leq H$, $w_t = [0, ..., 0, \varepsilon_t^g, \varepsilon_t^\mu, \varepsilon_t^\nu, \eta_t^1, \eta_t^2, ..., \eta_t^H, 0, ..., 0]'$, which collects the exogenous innovations, and $\zeta_t = [0, ..., 0,\ \zeta_t^x, \zeta_t^\pi, 0, ..., 0]'$, which collects the expectational errors $\zeta_t^x = x_t - E_{t-1}x_t$ and $\zeta_t^\pi = \pi_t - E_{t-1}\pi_t$. The rational-expectations model can be solved by standard techniques (e.g., Sims, 2000). The introduction of news shocks leads to an expanded state vector: for example, it increases from an 8×1 dimension for a model without news, to a 44×1 dimension if news up to eight periods ahead, i.e. $h = 1, 2, ..., 8$, are assumed.

We use the Metropolis-Hastings algorithm to generate draws from the posterior distribution. The likelihood at each iteration is obtained using the Kalman filter. We run 1,000,000 draws, discarding the first 250,000 as initial burn-in (we also ran various other chains starting from different initial values, using a different variance-covariance matrix for the MH proposal distribution, and updating the variance-covariance matrix after 500,000 draws based on the variance-covariance matrix for these parameter draws).

4. The Effects of Monetary Policy News and Surprises

4.1. **Optimal Horizon Length.** We start by estimating the baseline model in (2.1)-(2.6). The choice of a specific news horizon is somewhat arbitrary, therefore we chose to estimate the model using a wide range of possible horizon specifications and allow the relative marginal likelihoods of the models dictate our choice of news horizon.[6] The model is first estimated assuming news at each horizon from 1 to H, i.e. $h = 1, 2, ..., H$, with the maximum H ranging from 1 to 8; therefore, in this case, all intermediate horizons $1 \leq h \leq H$ are considered. The choice of including any intermediate horizon between 1 and H, however, considerably increases the size of the state space. Therefore, we also examine a more parsimonious choice by assuming that news shocks enter the model only with a specific horizon each time: we re-estimate the model for the case of $h = 1$, $h = 2$, and so forth, up to a maximum of $h = 12$. As an intermediate case, we also consider models with news at multiple horizons by estimating specifications with $h = 1, 4$, $h = 4, 8$, and $h = 4, 8, 12$. We cut the maximum horizon length at twelve quarters, since longer horizons become computationally unmanageable. Finally, for comparison, we also estimate the benchmark model without news shocks and report its fit.

The marginal likelihoods calculated for the baseline model under the different horizon structures are shown in the first column of Table 2. First, it can be noticed that the specification that shuts news down (i.e., the nested benchmark New Keynesian model) is outperformed by all but one specification that allows for news shocks (the overparameterized $h = 1, ..., 8$ specification has a slightly lower fit).

The best fit is obtained by the specification that allows for news shocks with selected multiple horizons equal to four, eight, and twelve quarters. The Bayes factor between the best-fitting model with news and the model without news is slightly above 28, which denotes between "strong" and "very strong" evidence in favor of the importance of news, according to Jeffreys' (1961) scale of evidence. The relatively long horizons signal that anticipations about the

[6]A similar approach is followed by Fujiwara et al. (2011).

Table 2. Model Comparison: Marginal Likelihoods

News Horizon	Baseline Model (News about MP)	TV Inflation Target (News about MP)	Perm+Trans News Shocks (News about MP and Target)	Multiple News Shocks (News about g_t, μ_t, and MP)
No News	-283.03	-280.64	-280.64	-283.03
$h = 1$	-282.64	-279.88	-279.88	-281.80
$h = 2$	-282.57	-279.58	-280.34	-286.71
$h = 3$	-282.82	-279.27	-279.70	-286.35
$h = 4$	-280.81	-278.06	-277.11	-281.96
$h = 5$	-282.72	-279.44	-279.60	-285.68
$h = 6$	-283.69	-280.12	-279.87	-283.02
$h = 7$	-281.04	-277.45	-277.38	-280.42
$h = 8$	-282.98	-277.55	-278.37	-278.17
$h = 9$	-280.89	-277.40	-277.83	-277.60
$h = 10$	-282.78	-280.92	-279.58	-278.77
$h = 11$	-281.40	-278.02	-281.58	**-276.74**
$h = 12$	-280.89	-280.62	-279.91	-276.89
$h = 1, 4$	-280.99	-276.65	-279.35	
$h = 4, 8$	-280.62	-276.45	**-276.49**	
$h = 4, 8, 12$	**-279.69**	**-275.56**		
$h = 1, 2$	-281.76			
$h = 1, 2, 3$	-281.96			
$h = 1, ..., 4$	-280.61			
$h = 1, ..., 5$	-282.01			
$h = 1, ..., 6$	-280.69			
$h = 1, ..., 7$	-281.80			
$h = 1, ..., 8$	-283.65			

Notes: The table shows the marginal likelihoods calculated using Geweke's harmonic mean approximation for alternative horizons for the news shocks and for alternative model specifications. The best-fitting model specifications and news structures are shown in bold.

direction of monetary policy over the medium term may be as important, or possibly even more important, than short-term surprises in affecting economic activity and inflation.

Since the model comparison identifies four, eight, and twelve quarters as the optimal horizon structure, in the following sections, we present all the results (such as posterior estimates, impulse responses, and variance decompositions) obtained under that case.

4.2. **Posterior Estimates.** Table 3 shows the mean posterior estimates, along with the corresponding 95% credible intervals, obtained for the best-fitting specification with a news shock with horizons equal to four, eight, and twelve quarters. It should be pointed out, however, that the posterior estimates for the structural coefficients are not really sensitive to the different horizon assumptions. The main focus of the paper lies in the estimates of the standard deviations of the surprise and news monetary policy shocks. The posterior mean for the standard deviation of the conventional unanticipated monetary policy shock is 0.078, while the standard deviations for the news shocks with anticipation horizons equal to four period, eight period, and twelve period ahead are 0.119, 0.099, and 0.089. Four-period-ahead news shocks, therefore, appear the most important over the sample, although news at longer horizons also matter. These findings remain consistent across the different news structure specifications that have been estimated. When the model is re-estimated using Uniform priors for the shocks standard deviations, the posterior estimates lead to very similar conclusions (see section 5.3).

Turning to the other coefficients, the estimates indicate that large degrees of habit formation in consumption and inflation indexation are necessary to fit the data ($\phi = 0.909$ and $\gamma = 0.88$). These estimates are somewhat higher than the corresponding estimates in Smets and Wouters (2007): the higher habit formation coefficient likely reflects the fact that here habits need to capture the persistence of output (rather than consumption) in a model that abstracts from capital, investment, and a variety of adjustment costs, which are all present in the Smets and Wouters' model. The serial correlation of the IS and Phillips curve shocks are, however, much lower than in Smets and Wouters: ρ_μ has a posterior mean equal to 0.037 and ρ_g equal to 0.426. It should be noted that a second mode exists (although it is associated to a lower posterior probability), and it is characterized by a low degree of indexation, but an autoregressive coefficient ρ_μ in the supply disturbance close to 0.9 (even under this second mode, however, the values of the other coefficients remain similar, and the real effects of surprise and news shocks unchanged). The trade-off between the estimated degree of intrinsic persistence in inflation, captured here by the indexation assumption, and the estimated serial correlation of exogenous supply shocks, is ubiquitous in the literature.

The other estimates are in line with the literature. The Taylor rule coefficients display posterior estimates equal to 1.529 for the response to inflation and 0.359 for the response to the output gap, with partial adjustment coefficient $\rho = 0.877$. The Calvo coefficient lies on the upper range of estimates at 0.898, but it's not uncommon.

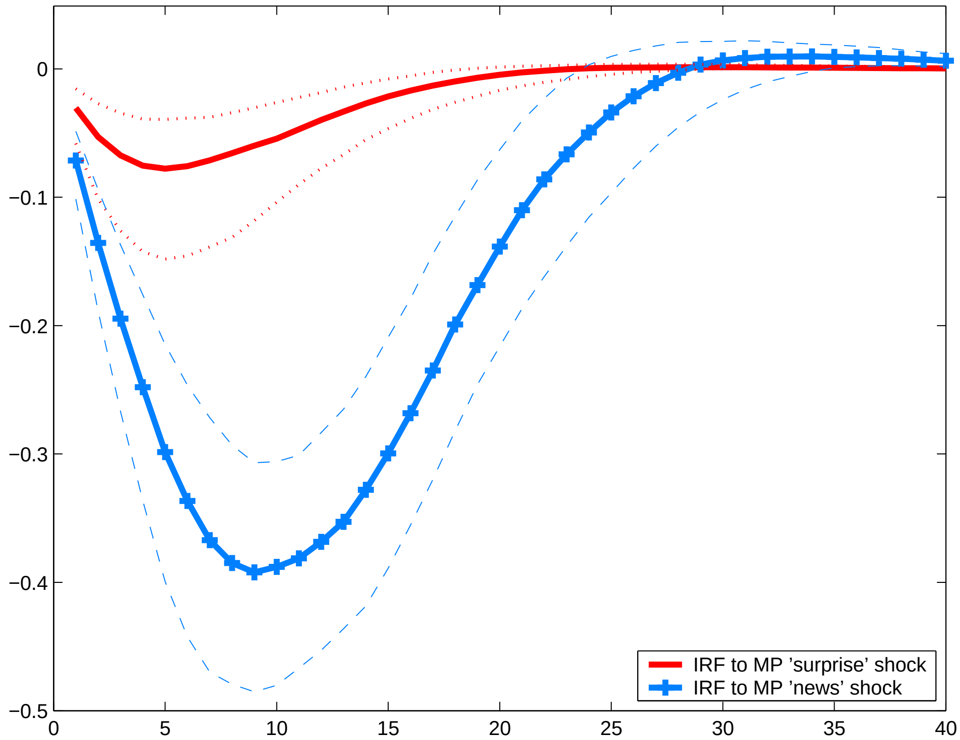
Table 3. Posterior Estimates

		Posterior Distributions				
Description	Param.	Baseline	Infl. Target	Target and News	Multiple News	Uniform Priors
Calvo price stick.	α	0.898 [0.83,0.96]	0.894 [0.82,0.96]	0.891 [0.81,0.95]	0.889 [0.81,0.95]	0.900 [0.83,0.96]
MP Inertia	ρ	0.877 [0.83,0.92]	0.885 [0.83,0.92]	0.881 [0.83,0.92]	0.889 [0.83,0.93]	0.881 [0.83,0.92]
MP Inflation feedback	χ_π	1.529 [1.15,1.92]	1.498 [1.04,1.92]	1.451 [0.98,1.88]	1.470 [1.07,1.83]	1.489 [1.06,1.93]
MP Output feedback	χ_x	0.359 [0.22,0.52]	0.395 [0.24,0.58]	0.391 [0.24,0.56]	0.405 [0.24,0.55]	0.380 [0.23,0.55]
Habit Formation	ϕ	0.909 [0.76,0.97]	0.832 [0.60,0.95]	0.873 [0.72,0.96]	0.784 [0.43,0.92]	0.865 [0.56,0.96]
Price Indexation	γ	0.88 [0.80,0.96]	0.346 [0.11,0.63]	0.254 [0.12,0.43]	0.360 [0.20,0.52]	0.316 [0.10,0.64]
AR coeff. g_t	ρ_g	0.426 [0.25,0.69]	0.550 [0.29,0.85]	0.483 [0.26,0.71]	0.268 [0.05,0.72]	0.491 [0.27,0.85]
AR coeff. μ_t	ρ_μ	0.037 [0.00,0.10]	0.095 [0.01,0.27]	0.136 [0.02,0.27]	0.081 [0.02,0.19]	0.108 [0.01,0.25]
AR coeff. ν_t	ρ_ν	0.236 [0.10,0.37]	0.244 [0.11,0.40]	0.270 [0.12,0.46]	0.246 [0.09,0.38]	0.257 [0.10,0.46]
Std. Demand Shock	σ_g	0.275 [0.19,0.34]	0.240 [0.15,0.33]	0.262 [0.19,0.34]	0.293 [0.20,0.37]	0.258 [0.15,0.34]
Std. Cost-Push Shock	σ_μ	0.157 [0.14,0.17]	0.166 [0.14,0.19]	0.164 [0.14,0.19]	0.164 [0.14,0.18]	0.165 [0.14,0.19]
Std. Surprise MP Shock	σ_ν	0.078 [0.02,0.19]	0.056 [0.02,0.14]	0.058 [0.02,0.16]	0.053 [0.02,0.12]	0.057 [0.00,0.15]
Std. 4q News Shock	$\sigma^\nu_{\eta,4}$	0.119 [0.02,0.22]	0.142 [0.03,0.23]	0.143 [0.02,0.23]		0.131 [0.01,0.22]
Std. 8q News Shock	$\sigma^\nu_{\eta,8}$	0.099 [0.02,0.21]	0.090 [0.02,0.21]	0.124 [0.02,0.23]		0.090 [0.00,0.21]
Std. 12q News Shock	$\sigma^\nu_{\eta,12}$	0.089 [0.02,0.21]	0.088 [0.02,0.20]			0.104 [0.00,0.21]
Std. Permanent Target Shock	σ_v		0.085 [0.04,0.13]	0.103 [0.07,0.14]		0.090 [0.04,0.14]
Std. 4q Target News Shock	$\sigma^{\pi^*}_{\eta,4}$			0.005 [0.001,0.02]		
Std. 8q Target News Shock	$\sigma^{\pi^*}_{\eta,8}$			0.003 [0.001,0.01]		
Std. 11q D News Shock	$\sigma^g_{\eta,11}$				0.204 [0.09,0.37]	
Std. 11q S News Shock	$\sigma^\mu_{\eta,11}$				0.063 [0.04,0.09]	
Std. 11q MP News Shock	$\sigma^\nu_{\eta,11}$				0.213 [0.18,0.24]	

Notes: the table reports posterior mean estimates for each parameter and the corresponding 95% Highest Posterior Density (HPD) intervals.

4.3. **What are the Effects of News Shocks?** At each MCMC draw, we compute the impulse responses to one-standard-deviation contractionary monetary policy shocks. Figures 1 and 2 compare the impulse response functions of both the output gap and inflation to the surprise monetary policy shock and to the news shocks, obtained for the optimal-horizon model (the figures report mean responses across draws, along with the corresponding 17% and 83% percentiles, and they show the sum of the responses to news shocks at the four, eight, and twelve anticipation horizons). The news shocks have a larger and more delayed effect compared to surprise shocks. The response to news reaches its negative peak around eight-nine quarters after the original shock. Since the estimates suggest a large degree of policy inertia, current

FIGURE 1. Impulse response function of the output gap to one-standard-deviation unanticipated ('surprise') and anticipated ('news') MP shocks.

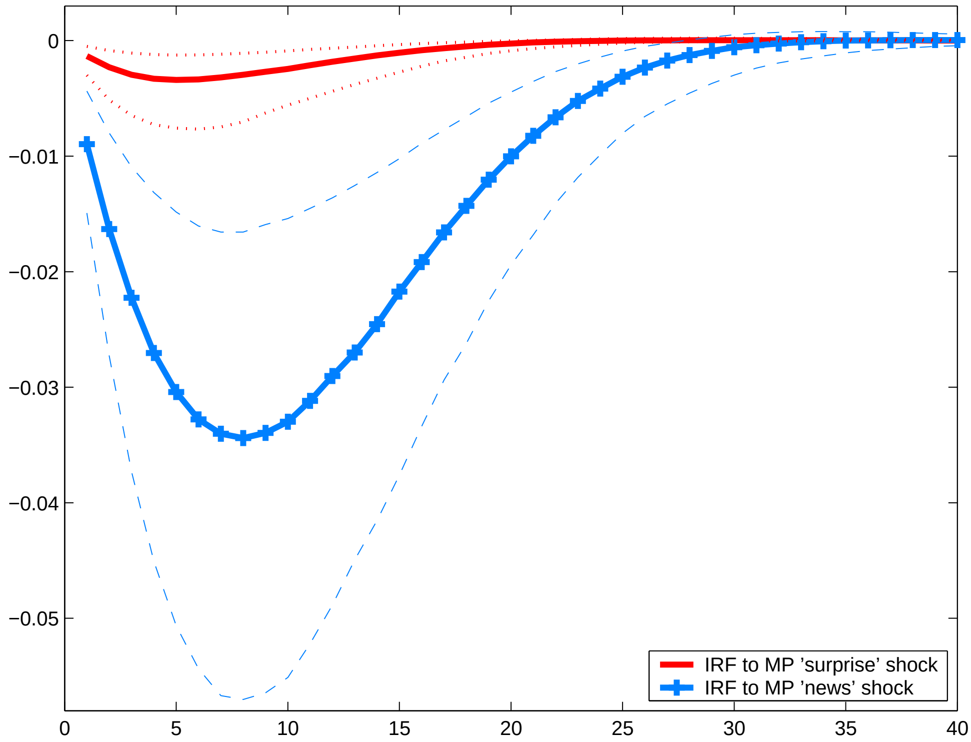


Notes: The figure displays the median impulse responses across MCMC draws, together with 17% and 83% percentiles.

news may provide valuable information not only about upcoming policy decisions, but also about the direction of interest rate changes in the medium term. Hence, the real effects induced by anticipated policy innovations are magnified.

Figure 3, instead, compares the response of the output gap to a standard monetary policy shock, which is calculated from an estimated model with only surprise shocks and the news channel shut down, with the previous mean responses to surprise and news shocks. Conventional estimates of the response to an exogenous monetary policy shock confound two rather different responses. The response of the output gap to an exogenous surprise shock to monetary policy reaches its negative peak sooner (roughly in the fourth quarter, rather than in the fifth-sixth quarter) and it becomes more short-lived when the news component is taken into account (reverting to zero almost two years earlier than otherwise estimated). News, instead,

FIGURE 2. Impulse response function of inflation to one-standard-deviation unanticipated ('surprise') and anticipated ('news') monetary policy shocks.



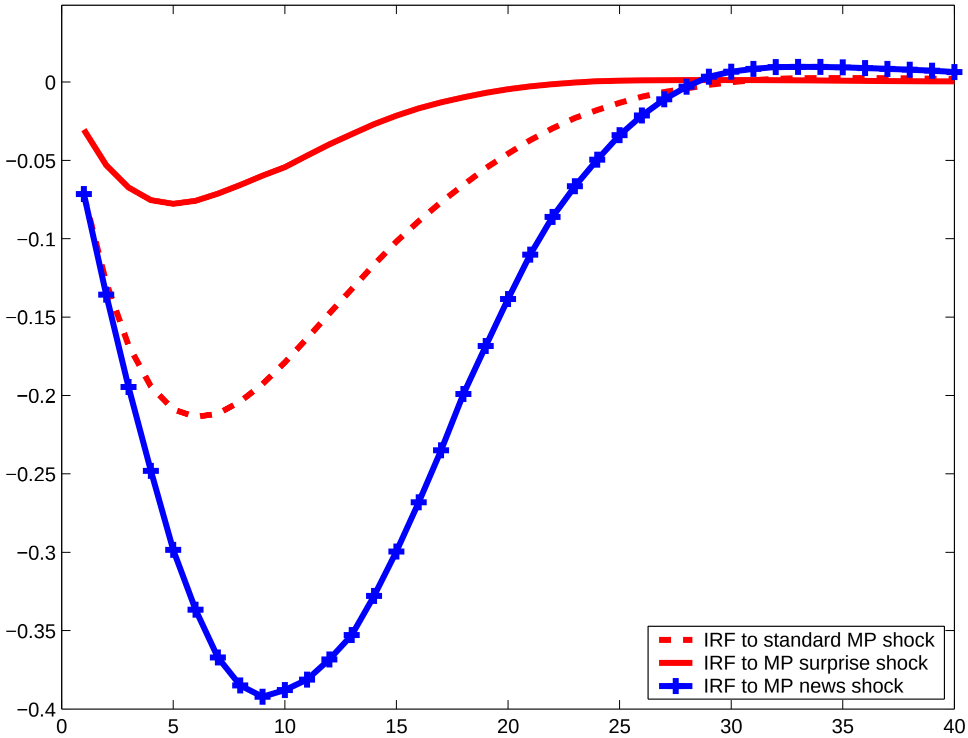
Notes: The figure displays the median impulse responses across MCMC draws, together with 17% and 83% percentiles.

produces a larger and more sluggish effect than the one implied by conventional estimates of the unexpected policy shock.

Figure 4 shows the outcome of the forecast error variance decomposition, calculated across MCMC draws, and for a medium-term horizon (32 quarters).[7] The upper plot shows the posterior distribution for the percentage of output gap variance due to the surprise monetary policy shock in the benchmark New Keynesian model that is estimated without allowing for news, while the lower plot overlaps the posterior distributions for the percentages of the output gap variance that can be attributed to surprise versus news shocks in the model with news. Conventional monetary policy shocks explain roughly between 3 and 18% of output gap fluctuations, with a mode around 8%. In the model that distinguishes between anticipated and unanticipated components, surprise shocks account for a much smaller fraction of fluctuations

[7]The conclusions for shorter horizons are not very different.

FIGURE 3. Impulse response functions of the output gap to one-standard-deviation MP shocks.



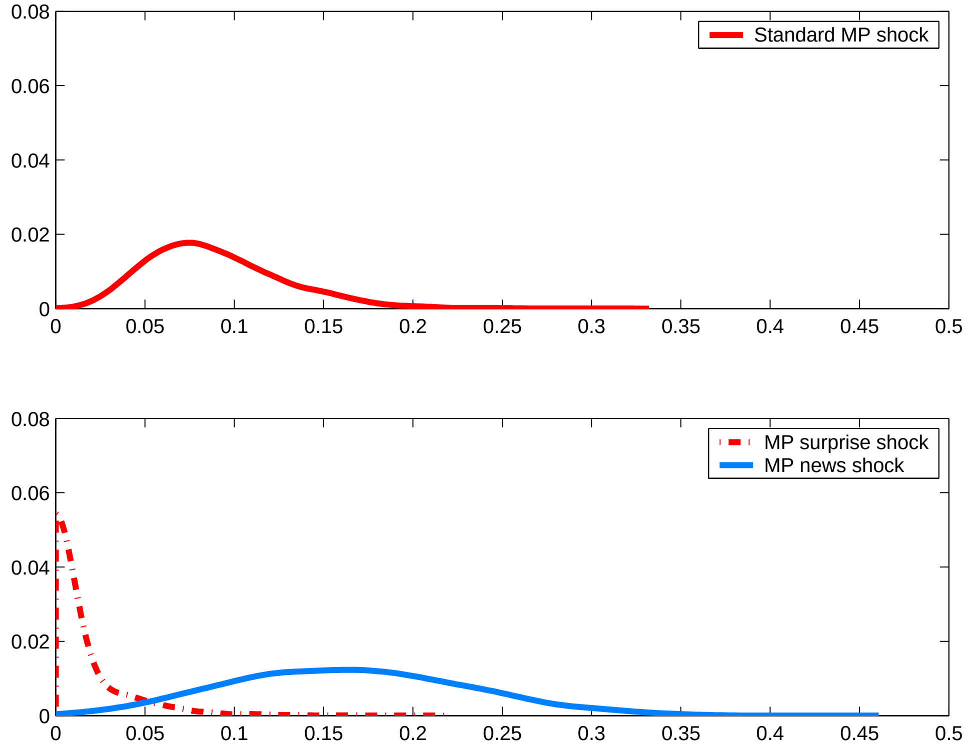
Notes: the figure shows the impulse response functions (median across draws) of the output gap to a one-standard-deviation monetary policy shock in a model with no 'news' (solid red line), versus the impulse response functions to one-standard-deviation unanticipated ('surprise') shocks (dashed red line) and the sum of the impulse responses to anticipated ('news') monetary policy shocks (blue line).

(with most probability mass below 5%, with posterior mean around 2%), while news shocks are substantially more important as they explain between 0 and 30% of the output gap variance, with a mean equal to 16%.

Overall, however, the conclusion that monetary policy shocks can account for only a limited portion of business cycle fluctuations, compared with other demand and supply shocks (which explain 70% and 12% of the variance), remains true in a model with news.

4.4. **Monetary Policy News and VAR Analyses.** The paper has used a small-scale DSGE model to disentangle unanticipated and anticipated monetary policy shocks and study their effects. This choice is motivated by the obstacles in correctly identifying shocks from structural VARs when forward-looking behavior and policy anticipations are a feature of the data. Leeper et al. (2008), for example, show how anticipations about future fiscal policy changes create

FIGURE 4. Forecast Error Variance Decomposition: posterior distribution of the percentage of output gap variance due to monetary policy shocks.



Notes: the upper plot shows the posterior distribution for the percentage of output gap variance explained by the standard monetary policy shock (exogenous unanticipated shock in an estimated model with no news); the bottom plot shows the posterior distributions for the percentage of output gap variance explained by the unanticipated (‘surprise’) and anticipated (‘news’) monetary policy shocks (sum over the news shocks across anticipation lengths).

econometric problems in standard VARs, due to the resulting non-invertibility, and make it impossible to identify the correct response to structural shocks. While Leeper et al. focus on fiscal policy, the issue, as they also stress, is more general and it may contaminate the results in other examples where a certain degree of anticipation is present.

This section provides further evidence that VAR analyses may suffer from a similar problem here and that they may fail to recover the macroeconomic responses to policy shocks.

We simulate the best-fitting model with monetary policy surprise and news shocks with anticipation horizons equal to four, eight, and twelve quarters. The parameters are fixed at their posterior mean estimates and the model is simulated 5,000 times to generate series that match the sample length used in the estimation (i.e., $T = 196$). For each simulation, we mirror

Table 4. VARs in the presence of monetary policy anticipations.

	MP Surprise Shock	VAR MP Shock	MP News Shock
Output Gap Impulse Response Peak	5	7.61 [6,10]	9
Share of Output Gap Variance	0.016	0.045 [0.0,0.0]	0.16

Notes: The table compares the impact of monetary policy 'surprise' and 'news' shocks implied by the model with the results that an econometrician would obtain by estimating a VAR on data generated from the model with news and the monetary policy shock identified through a Cholesky decomposition, as customary in the literature. The first row reports the peak quarters of the output gap impulse response function to the anticipated and unanticipated monetary policy shocks in the model and to those identified from the VAR. The second row shows the share in output gap forecast error variance decomposition that can be attributed to the policy shock. We run 5,000 simulations, constructing samples of length $T = 196$ each time (the model parameters are fixed at their posterior mean estimates). The numbers in the VAR column correspond to the mean from the simulation, while the numbers in square brackets denote 2.5 and 97.5 percentiles.

the case of an econometrician who estimates a monetary VAR on the model's endogenous variables – output gap, inflation, and the nominal interest rate – and obtains the response of the output gap to a monetary policy shock identified through a conventional Cholesky decomposition. We estimate the VAR and store the implied impulse responses and variance shares from the forecast error variance decomposition. We then check whether the VAR can recover the correct response to the structural monetary policy shock.

Table 4 provides some statistics that demonstrate that the VAR fails to identify the actual response from the simulated theoretical model. In particular, the VAR overstates the delay and persistence of the response to an unanticipated monetary policy shock. While the negative peak of the output gap response to a surprise shock appears five quarters after the shock and that to a news shock after nine quarters, the estimated response from the VAR concludes that the response reaches its peak, on average, between seven and eight quarters after the shock. Unanticipated shocks account for less than 2% of aggregate fluctuations in the model, while news shocks account for a larger share at 16%; VARs overstate the importance of unanticipated shocks, with a mean share around 5%.

Moreover, the monetary policy shock identified from the VAR does not correspond to the structural monetary policy shock, but rather to a weighted average of all structural shocks (Leeper et al., 2008, argue this point using a small theoretical model about tax policy shocks). The VAR shock is indeed similar to the corresponding structural shock (their correlation is equal to 0.78), but it also spuriously captures the role of the other structural shocks, as the natural rate demand shock and the supply shock (with which it has correlations equal to 0.42 and 0.36, rather than 0).

4.5. **Policy Implications: Central Bank Communication.** The paper's findings regarding the role of anticipated policy shocks provide yet another argument in support of a critical role for central bank communication. The results suggest that credible policy announcements by policymakers are likely to yield larger effects than attempts to surprise the markets through unexpected monetary policy decisions. In particular, the model comparison analysis reveals how anticipations that refer to medium-term horizons, here at least at one-year, two-year, and three-year horizons, seem to be those that matter the most.

From a methodological point of view, the paper offers an approach to study the quantitative effects of communication on macroeconomic variables. As Blinder et al. (2008) discuss, while an extensive empirical literature exists on the impact of central bank communication on financial markets, facilitated by the availability of high-frequency data whose behavior around policy announcements can be studied, there's still scant evidence on its consequences on the real economy. The identification of the impact of communication on macroeconomic variables, in fact, is complicated by the long lags in the transmission of policy to the economy and the greater degree of time aggregation in the data. Estimated general equilibrium models represent a possible environment in which communication can be studied, but they typically restrict the analysis to the effects of policy shocks that are unexpected by the private sector. This paper, instead, provides an environment in which it is possible to investigate the macroeconomic impact of central bank communication, in the form of news about future monetary policy shocks.

Indeed, a very recent paper by Hirose and Kurozumi (2011) actually tackles this issue by building on the approach used in this paper. They similarly add anticipated Taylor rule disturbances to their model and confirm the role of anticipated shocks found here, by including bond yields data in the estimation. Moreover, they study changes in the Fed's communication strategy over the Greenspan-Bernanke period and find evidence that the role of anticipated shocks with respect to unanticipated shocks has increased from the mid-1990s, when monetary policy-making was made more transparent.

5. Robustness

5.1. **Permanent and Transitory Monetary Policy Shocks.** The baseline model included only transitory monetary policy shocks. News, however, may spuriously capture the persistent effect of permanent shocks, which were here absent. This section presents an extension that allows us to separate between permanent and transitory monetary policy shocks. The inclusion of both permanent and transitory shocks is in line with the news literature, which, in a different context, typically assumes permanent and transitory shocks to technology.[8] To include permanent monetary policy shocks, we expand the model to include a time-varying inflation target. The monetary policy rule becomes

$$i_t = \rho i_{t-1} + (1-\rho)\left[\pi_t^* + \chi_\pi \left(\pi_t - \pi_t^*\right) + \chi_x x_t\right] + \nu_t, \tag{5.1}$$

where, for now, we assume that $\pi_t^* = \pi_{t-1}^* + v_t$. The prior choice regarding the standard deviation σ_v of the inflation target shock follows Milani (2009). Another difference in the model is that the inflation rate now enters the Phillips curve in deviation from the time-varying inflation target (this is similar to Smets and Wouters, 2007, and it arises from the assumption that firms index their prices to the inflation target).

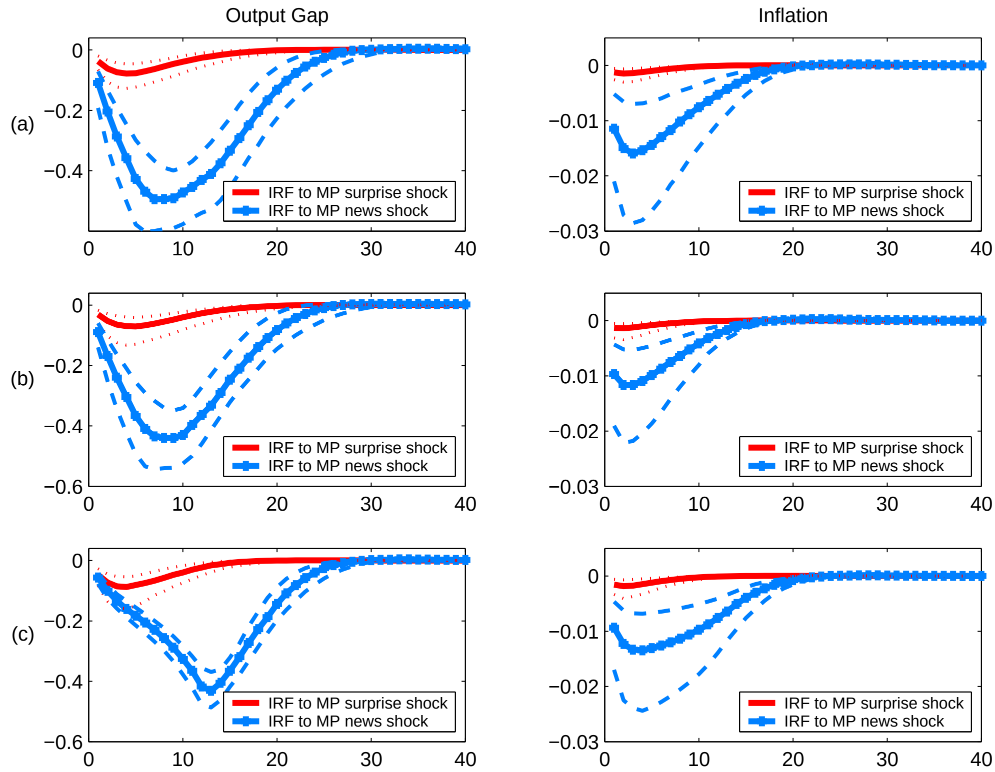
The model with the time-varying inflation target is re-estimated for an extensive range of horizon structures as done for the baseline case (we omit the specifications with all the intermediate h horizons, for brevity, and because they didn't seem to improve the fit). Table 2 (second column) reports the marginal likelihoods. Again, the best-fitting specification includes news with anticipation horizons equal to four, eight, and twelve quarters. And again, all models with news, except one, fit the data better than the benchmark New Keynesian model without news. The Bayes factor in this case is equal to 161, even larger than before, and corresponding to 'decisive' evidence according to Jeffrey's interpretative scale.

The main difference in the posterior estimates lies with the estimate of the indexation parameter. In the model that allows for a time-varying inflation target, the degree of indexation falls from 0.88 to 0.346. The other estimates remain similar.

News, so far, has only referred to future transitory monetary policy shocks. News, however, may also be related to future permanent shocks to the inflation target. The target equation

[8]Moreover, whether news refer to permanent or transitory shocks may have important implications for model dynamics, in light of the results in Fujiwara (2010).

FIGURE 5. Impulse response function of output gap and inflation to one-standard-deviation unanticipated (‘surprise’) and anticipated (‘news’) monetary policy shocks: robustness across different model specification.



Notes: Each panel in the figure displays the median impulse responses across MCMC draws, together with 17% and 83% percentiles. The top panels show the responses for the model with the permanent inflation target shocks, the medium panels show the responses for the model with the inflation target shocks and news about the target, and the bottom panels show the responses for the model with news about demand, supply, and policy shocks. The left column shows responses of the output gap, while the right column shows responses of inflation.

in the model with news about permanent and temporary shocks becomes $\pi_t^* = \pi_{t-1}^* + v_t + \sum_{h=1}^{H} \eta_{t-h}^{v,h}$. The model is re-estimated for all the previous horizons, with the exception of the $h = 4, 8, 12$ structure, which becomes exceedingly cumbersome to estimate, given the addition of a new set of news shocks.

The empirical results are unchanged. The posterior mean estimates for the standard deviations of news regarding future target shocks equal 0.005 and 0.003 for the four-quarter and eight-quarter horizons, which are included in the best-fitting specification. News about future transitory monetary policy shocks still matter, while news about inflation target changes appear less important.

Figures 5 and 6 analyze the sensitivity of the paper's conclusions to different modeling choices. The upper and medium panels in Figure 5 show the impulse responses of output gap and inflation to the surprise and news shocks, which are obtained in the best-fitting model with the time-varying inflation target and in the best-fitting model that also adds news about the target. The upper and medium panels in Figure 6 show the distributions for the shares of output gap variance that can be attributed to unanticipated transitory shocks, unanticipated permanent shocks, and anticipated news shocks, in the same two model specification. The output gap responses are similar to those obtained for the baseline model: they are larger, more delayed, and more persistent for news shocks than for policy surprises. The inclusion of permanent inflation target shocks, instead, seems to reduce the delay and persistence of the inflation response to news shocks. The variance decomposition results are robust: anticipated monetary policy shocks account for roughly 20-25% of output gap fluctuations, while temporary and permanent shocks account for less than 5%.

5.2. **News about Supply, Demand, and Monetary Policy Shocks.** News may also be related to future demand and supply shocks. So far the analysis has ruled out this possibility, but, for the scope of this paper, it is important to verify that the results regarding monetary policy shocks are not sensitive to this modeling assumption. Therefore, to assess their sensitivity, we again re-estimate the model, now allowing news to affect g_t and μ_t as follows:

$$g_t = \rho_g g_{t-1} + \varepsilon_t^g + \sum_{h=1}^{H} \eta_{t-h}^{g,h} \tag{5.2}$$

$$\mu_t = \rho_\mu \mu_{t-1} + \varepsilon_t^\mu + \sum_{h=1}^{H} \eta_{t-h}^{\mu,h} \tag{5.3}$$

$$\nu_t = \rho_\nu \nu_{t-1} + \varepsilon_t^\nu + \sum_{h=1}^{H} \eta_{t-h}^{\nu,h}. \tag{5.4}$$

The model is estimated under each horizon h, $h = 1$, $h = 2$, to $h = 12$. The other cases are omitted, since the many news shocks now present in the model make the computation unfeasible. The third column in Table 2 shows the model comparison results, which reveal the specification with a long horizon equal to eleven quarters of anticipation as the best-fitting case (Bayes factor = 539 versus the no-news model).

The posterior estimates for the standard deviations of the shocks indicate that unanticipated shocks have a larger variance than anticipated shocks for the case of supply innovations, a slightly larger variance for demand shocks, and a considerably lower variance for monetary policy shocks. Interestingly, the degree of price indexation falls also when news about future supply shocks are added.

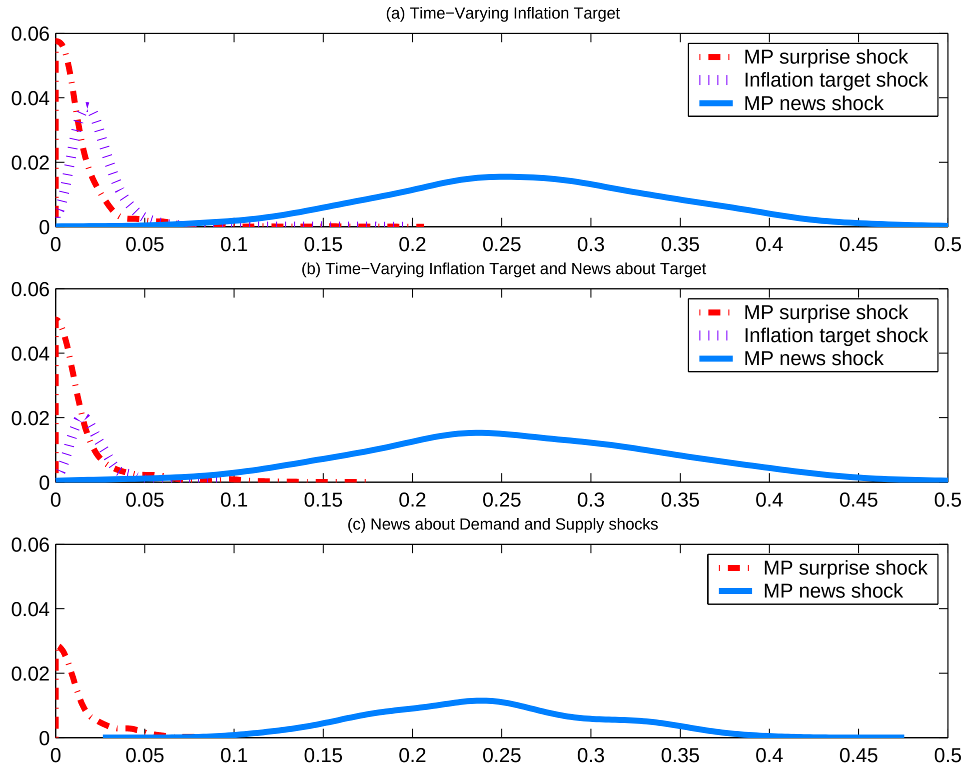
It is worth noting that this exercise represents the first study of the New Keynesian model in which all shocks are allowed to have an anticipated component. The model that features multiple types of news achieves the highest fit among all the considered specifications (if we restrict the attention to models with only news at one horizon at a time). This is only an indicative exercise, but the apparent goodness of fit suggests that a more rigorous analysis of the New Keynesian model with news about future demand, supply, and policy shocks (for example, allowing the anticipation horizons to differ across shocks), is likely to be a fruitful topic for future research.

The bottom panel of Figure 5 shows the impulse responses of the output gap and inflation to monetary policy surprise and news shocks. The response shapes are somewhat different as they refer in this case to a specification with only one anticipation horizon equal to eleven quarters. The conclusions, however, are not really different. News leads to large and delayed adjustments in the output gap, while the response of inflation is less sluggish than in the baseline case, now that news about demand and supply has been added as well. As shown in the bottom panel of Figure 6, the variance decomposition results regarding monetary policy shocks from the model with multiple news are in line with previous cases.

5.3. **Non-Informative Priors.** To assess the sensitivity of the estimates regarding surprise and news shocks, we re-estimate the model under non-informative Uniform prior distributions for the standard deviations of the shocks. We assume Uniform distributions between 0 and 1 for the standard deviation of the surprise shock ν_t and for the standard deviations of the news shocks η^4_{t-4}, η^8_{t-8}, and η^{12}_{t-12}. We hence re-estimate the specification, which includes a permanent inflation target and with anticipation horizons equal to four, eight, and twelve quarters, since it corresponds to the highest-fitting specification that has been encountered in the estimation.

The posterior estimates, shown in the last column in Table 3, provide evidence that the data are indeed informative on the choice between anticipated and unanticipated innovations. The posterior mean for σ_ν is equal to 0.057, and the posterior means for $\sigma_{\eta,4}$, $\sigma_{\eta,8}$, $\sigma_{\eta,12}$, fall close to

FIGURE 6. Forecast Error Variance Decomposition: posterior distribution of the percentage of output gap variance due to monetary policy shocks.



Notes: Each panel in the figure shows the posterior distribution of the output gap variance share that is explained by different types of monetary policy shocks. The top panel shows the variance share distributions for the model with the permanent inflation target shocks, the medium panel shows the distributions for the model with the inflation target shocks and news about the target, and the bottom panel shows the distributions for the model with news about demand, supply, and policy shocks.

their previous values obtained under the more informative inverse Gamma priors ($\sigma_{\eta,4} = 0.131$, $\sigma_{\eta,8} = 0.09$, and $\sigma_{\eta,12} = 0.104$). The implied impulse responses and variance decomposition shares (not shown) remain similar to those previously discussed.

6. Conclusions

The literature on monetary policy is characterized by a substantial agreement regarding the effects of exogenous monetary policy shocks on variables such as output and inflation. While most of the literature exclusively treats monetary policy shocks as unexpected by the private sector, this paper has separated the shocks into an unanticipated or "surprise" component, and an anticipated or "news" component.

The paper consequently shows that the approach of treating all monetary policy innovations as surprises seems to aggregate the effect of the true monetary surprise, which has a very small, but immediate, effect, with the anticipated or news shock which has a much larger and more persistent effect on the economy. Moreover, since the contribution of monetary policy news to output fluctuations is larger than the contribution of surprise shocks, our results suggest that communication by the central bank, such as the current practice of hinting about future deviations from systematic policy, is important in achieving a larger impact on the economy.

APPENDIX A - Model Derivation.

This section outlines the derivation of the model equations in (2.1)-(2.3), which is now standard in the New Keynesian literature (e.g., Woodford, 2003). A similar model, without news shocks, has been estimated, for example, in Dennis (2004, 2009).

Each household solves the following optimization problem

$$\max_{C,L,B} E_0 \sum_{t=0}^{\infty} \beta^t \left[e^{\tilde{g}_t} \frac{(C_t - \phi C_{t-1})^{1-\sigma^{-1}}}{(1-\sigma^{-1})} - \frac{L_t^{1+\chi}}{1+\chi} \right] \tag{6.1}$$

subject to the period budget constraint

$$C_t + \frac{B_t}{P_t} = W_t L_t + \frac{(1+R_{t-1})B_{t-1}}{P_t} + \frac{D_t}{P_t} - T_t. \tag{6.2}$$

Each household, therefore, derives utility from consumption C_t and disutility from hours of labor supplied L_t. The utility function is characterized by external habit formation, i.e., consumers value current consumption in relation to past aggregate consumption. The coefficient β denotes the discount factor, σ and χ denote the elasticities of intertemporal substitution and of labor supply, while ϕ measures the degree of habit formation. The term $e^{\tilde{g}_t}$ represents an aggregate shock that shifts consumers' preferences. Expected discounted lifetime utility is maximized subject to the budget constraint (6.2), where B_t denotes nominal bond holdings, P_t denotes the aggregate price level, W_t the nominal wage, R_t the nominal interest rate, D_t dividend distributions from household-owned firms, and T_t are net transfers. The first order conditions imply

$$e^{\tilde{g}_t} (C_t - \phi C_{t-1})^{-\frac{1}{\sigma}} = \lambda_t \tag{6.3}$$

$$\lambda_t = \beta (1+R_t) (P_t/P_{t+1}) E_t \lambda_{t+1} \tag{6.4}$$

$$L_t^{\chi} = \lambda_t W_t. \tag{6.5}$$

From (6.3) and (6.4), we obtain the Euler equation, which is then loglinearized around a zero-inflation steady state to yield

$$c_t = \frac{1}{1+\phi} E_t c_{t+1} + \frac{\phi}{1+\phi} c_{t-1} - \frac{\sigma(1-\phi)}{1+\phi} (i_t - E_t \pi_{t+1} - \tilde{\rho} - \Delta \tilde{g}_{t+1}), \tag{6.6}$$

where $\tilde{\rho} = -\log \beta$ is the discount rate and $\tilde{g}_t = \log(e^{\tilde{g}_t})$. Small letter variables denote log deviations from the steady state $x_t = \log(X_t/X)$; i_t denotes the short-term nominal interest rate and π_t denotes the inflation rate.

The labor supply equilibrium condition (6.5), in loglinear terms, implies

$$\chi l_t - w_t - \tilde{g}_t = \frac{1}{\sigma(1-\phi)} (c_t - \phi c_{t-1}). \tag{6.7}$$

The loglinearized Euler equation can be re-expressed in terms of the output gap, by using the resource constraint $c_t = y_t$ and the output gap definition $x_t = y_t - y_t^*$:

$$x_t = \frac{1}{1+\phi} E_t x_{t+1} + \frac{\phi}{1+\phi} x_{t-1} - \frac{\sigma(1-\phi)}{1+\phi} (i_t - E_t \pi_{t+1}) + g_t \tag{6.8}$$

with $g_t = \frac{1}{1+\phi} \left[\sigma(1-\phi)(\tilde{\rho} + \Delta \tilde{g}_{t+1}) + \left[\left(y_{t+1}^* - \phi y_t^* \right) - \left(y_t^* - \phi y_{t-1}^* \right) \right] \right]$.

The production side of the economy is characterized by a continuum of monopolistically competitive firms. Prices are sticky à la Calvo: each firm has a $(1-\alpha)$ probability of re-optimizing its price in every period. Firms that are not allowed to optimize use the indexation rule proposed by Christiano et al. (2005):

$$\log p_t^i = \log p_{t-1}^i + \gamma \pi_{t-1}, \tag{6.9}$$

where γ measures the degree of indexation to past inflation.

Each firm maximizes the expected discounted stream of future profits given the demand curve for their product $y_t^i = \left(\left(p_t^i / P_{t+\tau} \right) \left(P_{t+\tau-1} / P_{t-1} \right)^{\gamma} \right)^{-\theta} Y_{t+\tau}$, and its production function $y_t^i = A_t \left(L_t^i \right)^{\eta}$:

$$\max_{p_t^*} E_t \sum_{\tau=0}^{\infty} \frac{(\alpha\beta)^{\tau} \lambda_{t+\tau}}{\lambda_t} \left[p_t^* \left(\frac{P_{t+\tau-1}}{P_{t-1}} \right)^{\gamma} \left(\frac{p_t^*}{P_{t+\tau}} \left(\frac{P_{t+\tau-1}}{P_{t-1}} \right)^{\gamma} \right)^{-\theta} Y_{t+\tau} \right.$$
$$\left. - W_{t+\tau} \left(\left(\frac{p_t^*}{P_{t+\tau}} \left(\frac{P_{t+\tau-1}}{P_{t-1}} \right)^{\gamma} \right)^{-\theta} \frac{Y_{t+\tau}}{A_{t+\tau}} \right)^{\frac{1}{\eta}} \right], \tag{6.10}$$

where p_t^* denotes the optimal price to be chosen, P_t denotes the aggregate price level, A_t denotes aggregate technology, θ indicates the elasticity of substitution among differentiated products, and η accounts for diminishing returns to scale. The first order condition can be expressed as

$$E_t \sum_{\tau=0}^{\infty} \frac{(\alpha\beta)^{\tau} \lambda_{t+\tau}}{\lambda_t} \left\{ (1-\theta) (p_t^*)^{-\theta-1} \left(\frac{P_{t+\tau-1}}{P_{t-1}} \right)^{\gamma} \left(\frac{1}{P_{t+\tau}} \left(\frac{P_{t+\tau-1}}{P_{t-1}} \right)^{\gamma} \right)^{-\theta} P_{t+\tau} Y_{t+\tau} \right.$$
$$\left. \times \left[\frac{p_t^*}{P_{t+\tau}} \left(\frac{P_{t+\tau-1}}{P_{t-1}} \right)^{\gamma} - \left(\frac{\theta}{\theta-1} \right) \frac{W_{t+\tau}}{P_{t+\tau} A_{t+\tau} \eta} \left(\left(\left(\frac{P_{t+\tau-1}}{P_{t-1}} \right)^{\gamma} \right)^{-\theta} \frac{Y_{t+\tau}}{A_{t+\tau}} \right)^{\frac{1-\eta}{\eta}} \right] \right\} = 0. \tag{6.11}$$

The aggregate price index evolves as

$$P_t = \left[(1-\alpha) (p_t^*)^{(1-\theta)} + \alpha \left(P_{t-1} \left(\frac{P_{t-1}}{P_{t-2}} \right)^{\gamma} \right)^{(1-\theta)} \right]^{1/(1-\theta)}. \tag{6.12}$$

Log-linearization of the first order conditions (6.11) and (6.12) yields

$$p_t^* = (1-\alpha\beta) E_t \sum_{\tau=0}^{\infty} (\alpha\beta)^{\tau} \left[\sum_{k=1}^{\tau} (\pi_{t+k} - \gamma \pi_{t+k-1}) + mc_{t+\tau} \right] \tag{6.13}$$

$$p_t^* = \frac{\alpha}{1-\alpha} (\pi_t - \gamma \pi_{t-1}), \tag{6.14}$$

where mc_t denotes real marginal costs and $p_t^* \equiv \log(p_t^*/P_t)$. By quasi-differentiating (6.13) and plugging (6.14) into (6.13), we obtain the New Keynesian Phillips curve, written in terms of the economy's aggregate marginal cost:

$$\pi_t = \frac{\beta}{1+\beta\gamma}E_t\pi_{t+1} + \frac{\gamma}{1+\beta\gamma}\pi_{t-1} + \frac{(1-\alpha)(1-\alpha\beta)}{\alpha(1+\beta\gamma)}mc_t. \tag{6.15}$$

The marginal cost is equal to the real wage minus the marginal product of labor $mc_t = w_t - a_t - (\eta-1)l_t$. The real wage is equal to marginal rate of substitution between consumption and leisure, given by $w_t = \chi l_t - \tilde{g}_t + \frac{1}{\sigma(1-\phi)}(c_t - \phi c_{t-1})$. Plugging in the production function, we have $w_t = \chi\eta^{-1}(c_t - a_t) - \tilde{g}_t + \frac{1}{\sigma(1-\phi)}(c_t - \phi c_{t-1})$. Therefore, the marginal cost is given by

$$mc_t = \left[\omega c_t + \frac{\sigma^{-1}}{1-\phi}(c_t - \phi c_{t-1}) - \frac{\chi+1}{\eta}a_t - \tilde{g}_t\right], \tag{6.16}$$

where $\omega = (\chi - (\eta-1))/\eta$. Finally, by using $c_t = y_t$, $x_t = y_t - y_t^*$, and the steady-state relation $mc = 1/\mu$, equation (6.15) can be re-expressed in terms of the output gap:

$$\pi_t = \frac{\beta}{1+\beta\gamma}E_t\pi_{t+1} + \frac{\gamma}{1+\beta\gamma}\pi_{t-1} + \frac{\xi}{(1+\beta\gamma)}\left(\omega x_t + \frac{\sigma^{-1}}{(1-\phi)}(x_t - \phi x_{t-1})\right) + \mu_t \tag{6.17}$$

where $\xi \equiv \frac{(1-\alpha)(1-\alpha\beta)}{\alpha}$; the term μ_t denotes a cost-push supply shock, which is sometimes simply appended to the model, but which is straightforward to derive endogenously by assuming a time-varying elasticity of substitution θ_t, instead.

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